An Overview of the SOAREX and TechEdSat Flight Series:

Missions To Advance Re-entry Experimentation, Planetary Mission Design, and Flight Technology

M.S. Murbach, SOAREX/TES-Team

IPPW-12

Koln, Germany

June 15 , 2015

Next-Up!

SOAREX-M/TechEdSat-N

Abstract

A series of sub-orbital flights (SOAREX - Sub-Orbital Aerodynamic Re-entry Experiments) and nano-satellite flights are described. These flights originated in 1998 with SOAREX-1 and most recently SOAREX-8 and TechEdSat-5 are planned for flight in 2015. The SOAREX flights have involved the use of both land (White Sands Missile Range) and water (Wallops Flight Facility)using a variety of rockets, jettison, data storage/telemetry techniques. The SOAREX-1 flight involved 11 independent entry experiments which included self-stabilization techniques, auto-initiated transpiration cooling, linear-aerobrake, Slotted-Compression Ramp Probe (SCRAMP)techniques as well as initial use of MEMs sensors. The next SOAREX flights involved work on stabilization and flight experimentation with high L/D on a 'modified-Hankey' type of geometry. SOAREX 6, 7 experiments included a 4km/s entry shock-interaction experiment, and advanced planetary probe design leading to the self-stabilizing Tube Deployed Re-entry Vehicle (TDRV). The complementary orbital series involved the nano-satellitemodular design with TechEdSat-1 (TES-1) being the first U.S. cubesat to be jettisoned from the International Space Station (ISS). TES-2 was the first demonstration of the use of an existing satellite network to greatly increase the data-rate from nano-satellites. TES-3 and TES-4 were both 3U nano-satellites which included advanced communication as well as the first small-scale Exo-Brake flight tests. TES-4 featured the first nano-satelltie to be commanded by email commands. All of the flight experiments were carried out with modest budgets and short timelines - embodying a 'rapid proto-flight' technique of developing the flight experiments.

Origins: Rapid 'Proto-Flight'

SOAREX-1 (Sub-orbital; 1998)

SOAREX-8 in development (7-7-15 launch)

TES-5 in development (complete 9-30-15)

To date:

* Multiple balloon flights (UofIdaho)
* 8 Sub-orbital payloads (+18 re-entry)
* 4 Nanosatellite experiments

Primary motivations:

-Rapidly advance SOA in various technology areas

-Student internship/mentoring

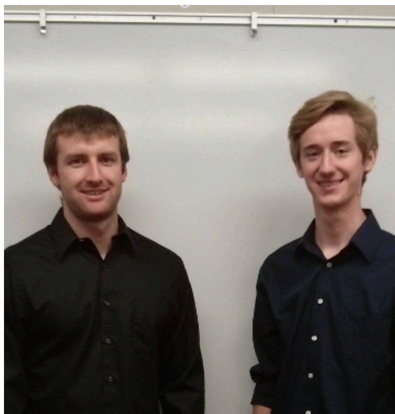
National Aeronautics and Space Administration

Ames
Discovery Innovations Solutions

Collaborations Have Been Numerous

Key: P. Papadopoulos/SJSU; D. Atkinson/U.of Idaho

Institutions: ARC, WFF, LaRC, SJSU, UofIdaho, UCR, USC, NRL, NPG,…



Summary/Platforms

Balloon:

VAST Program/University of Idaho Since 2006

Sub-orbital Flights – **SOAREX** (Sub-Orbital Aerodynamic Re-entry Experiments)

SOAREX-1	9-30-1998	Deployed 11 re-entry exps.
SOAREX-2	12-18-2002	Deployed 3 re-entry exps.
SOAREX-3	7-15-2003*	Deployed 1 proto-waverider
SOAREX-4/5	Delayed	Built – not flown; Dual waverider
SOAREX-6	9-28-2008*	Deployed 3 experiments; vehicle failed
SOAREX-7	5-28-2009	Deployed 1 TDRV
SOAREX-8	7-7-2015	**Full-scale Exo-Brake/ Adv COM/WSM**
SOAREX-9	Planned	In development

Orbital Flight – **TES** (TechEdSat-N)

TES-1	10-4-2012	First 1U U.S. CubeSat from ISS
TES-2	4-21-2013	First Iridium/COM experiment
TES-3	11-30-2014*	First Exo-Brake flight test
TES-4	3-4-2014	Adv COM/Control; Exo-Brake 2
TES-5	7-7-2015	**Modulated Exo-Brake/COM**

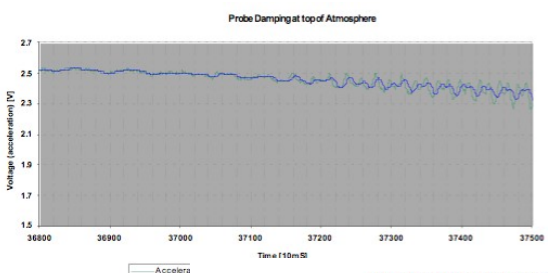
National Aeronautics and Space Administration

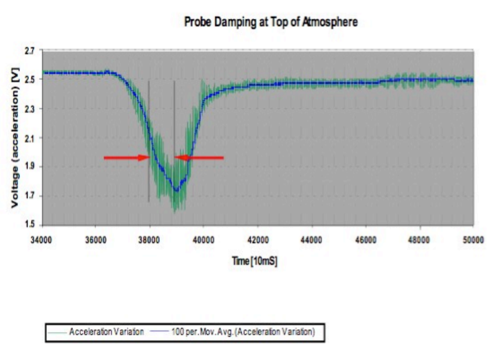
Ames

Discovery Innovations Solutions

SOAREX-1

Vehicle: Terrier- Black-Brant/36.150 (234km apogee)
Date: 12-30-1998
Approach: Axial deployment of 11 experiments/sabot; Minimal TM
Experiments Various- SCRAMP, Linear Aerobrake; T-piration cooling; empty duct stabilization



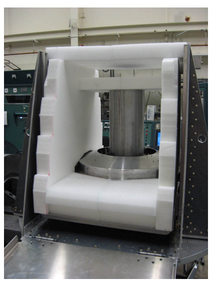


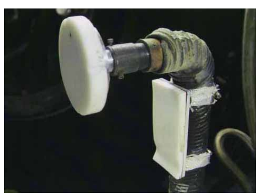
Key Attributes:

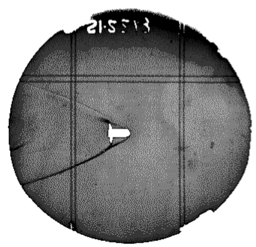
- Multiple-radial ejector system
- 10 ft. ejector (3 m)
- On-board data-storage (.1 kHz sample)
- ‘Wind tunnel in the sky’ concept
- WSMR launch permitted recovery
- ALL 11/11 experiments located
- Key experiments
  - dynamic stability of NSC and other
  - SCRAMP
  - Transpiration cooling technique
  - Linear aerobrake (stability at interface)
  - Duct stabilization/recovery

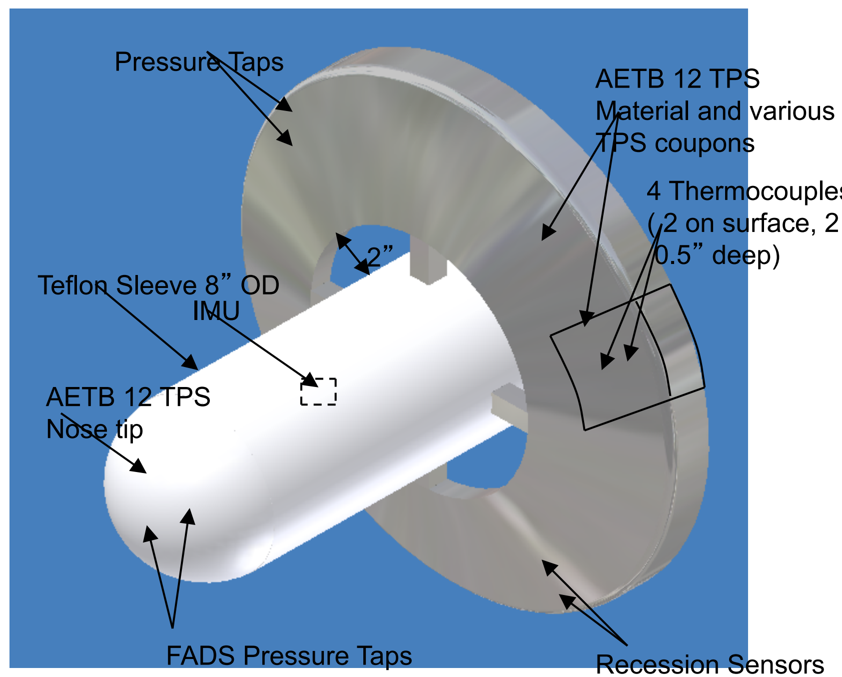
SOAREX-6

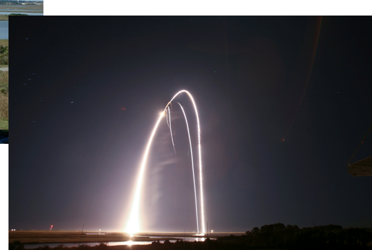
Vehicle: ATK Sub-orbital/Orion 50xl (4km/s entry velocity)
Date: Sept 27, 2008
Approach: Deployed < apogee; Interlocking SIRCA tiles on tail
Experiments: High Ve SCRAMP; Atm probe; early TDRV; ‘Long down-range’
Result: All experiments functioned in flight; vehicle ‘terminated’





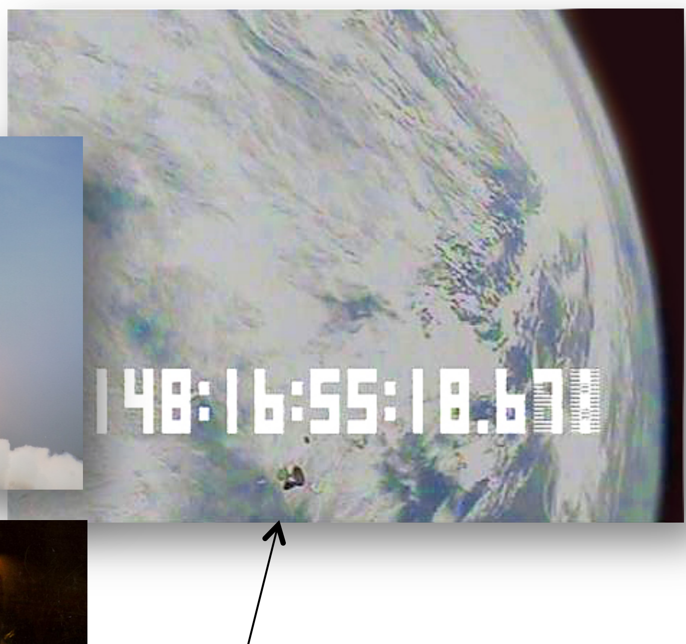


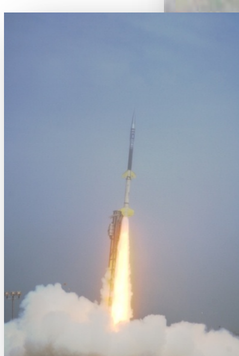


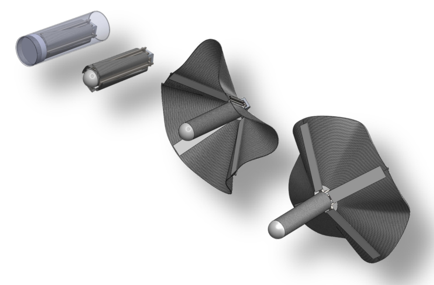


SOAREX-7

Vehicle:	Terrier-Orion (WFF launch; 134km apogee)
Date:	May 28, 2009
Approach:	Deployed < apogee; Axial ejection with cameras/TM
Experiments:	TDRV (Tube Deployed Re-entry Vehicle) flight test
Result:	Successful demonstration of self-stabilization/low-β design







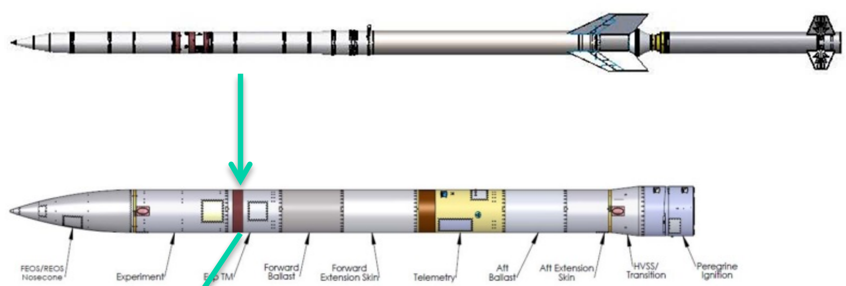
SOAREX-M/TechEdSat-N

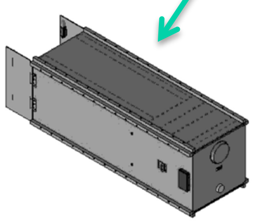
Key Attributes:

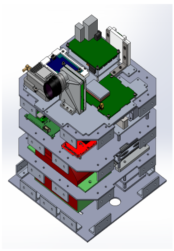
- Large static margin
- Self-orienting
- Low ballistic coefficient (order <10 kg/m2)
- Compact stowage (cylindrical)
- Both slot/no-slot versions investigated
- Hot-structure (unique flexible sandwich construction)
- TM (S-band/ C-band)

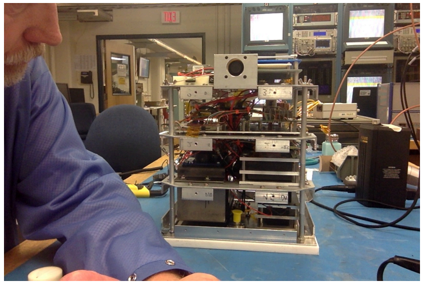
SOAREX-8

Vehicle: Terrier Black-Brant (formerly Terrier-Peregrine test flight
Date: 7-7-15 planned (very high certainty)
Approach: Forward ejection of '50U'; Nosecone experiments
Experiments: First 'full-scale' test of the Exo-Brake









Key Attributes:

- First 'full-scale' Exo-Brake deployment test
- 50U 'cubesat' or ½ scale SPQR
- X-band (2 W) / 10+ Mbs
- ISM-band (1 mW) 1 Mbs
- C-band transponder/ skin trackingi
- Wireless Sensor Module (WSM)
- Modular Manufacturable Cubesat Design

Mission Timeline/Success Criteria

Section 1.0 – Mission Manager
DR – 12.077/Brodell

Terrier-Peregrine 12.077 GT/Brodell
1100# P/L, 80.0° QE, 105° AZ, ARC, WFF

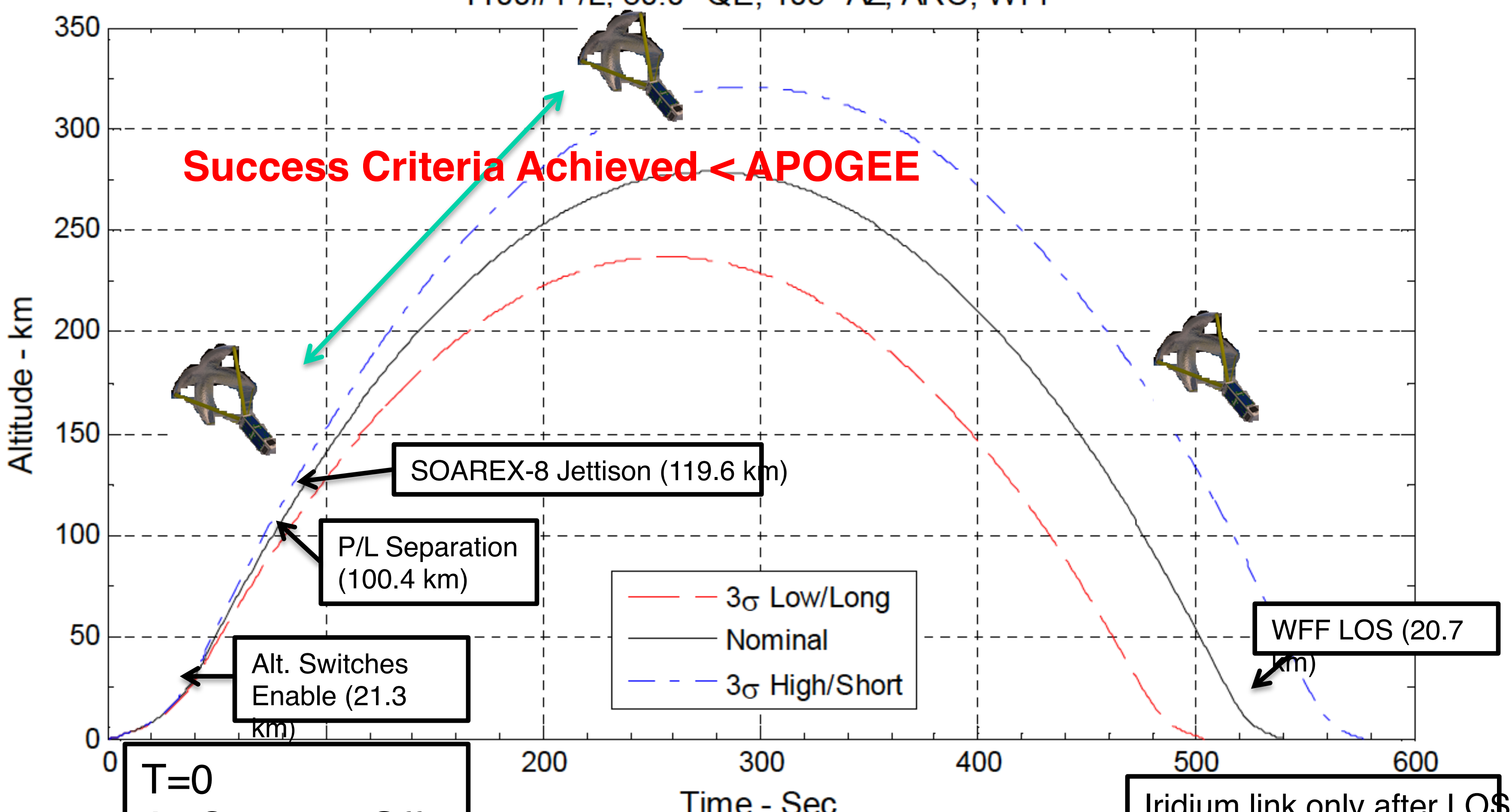


Figure 3.2-1. Altitude vs Time

Te

Re-entry Calculation (Nominal)

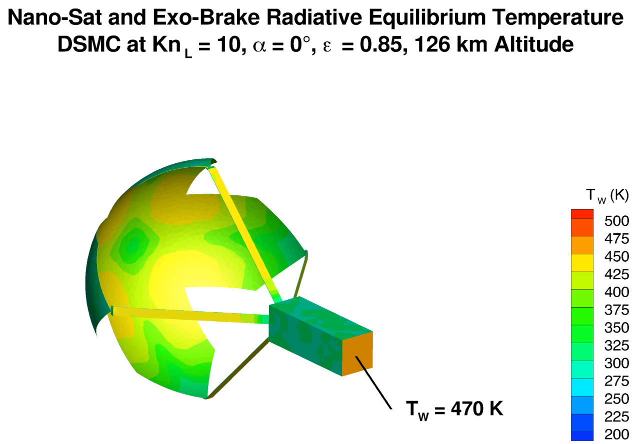
Typical TRAJ run; 350km Apogee:

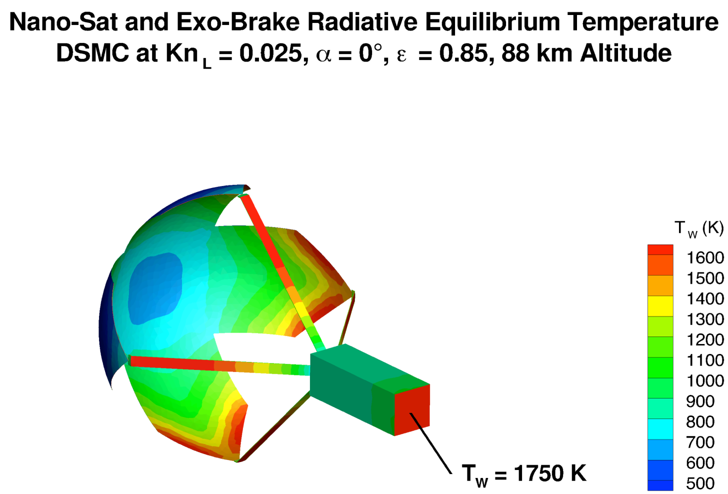
```
Integrator step size:  Minimum =  6.48e-02 sec., Last value = 1.000000 sec.
Vehicle impacted planet's surface at  1909.31 sec.,     8.95 meter/sec
```

Maximum Values					
Value	Quantity	Time (sec)	Altitude (km)	Velocity (km/sec)	Ball.Coef. (kg/m^2)
Deceleration Magnitude	133.60 m/sec^2 13.62 g	258.9	53.93	1.44	5.00
Dyn. Pressure	6.68e+02 pascals	258.9	53.93	1.44	5.00
Stg. Pressure	1.01e+05 pascals	1909.2	0.00	0.01	5.00
Cnv. Heat Flux	1.42 W/cm^2	253.2	63.84	2.03	5.00
Tot. Heat Flux	1.42 W/cm^2	253.2	63.84	2.03	5.00
Wall Temp.	747.92 K	Same as above line.			

(Time=0 at Apogee; recalculated 5-11-15)

Initial DSMC Calculations for Representative Nanosatellite

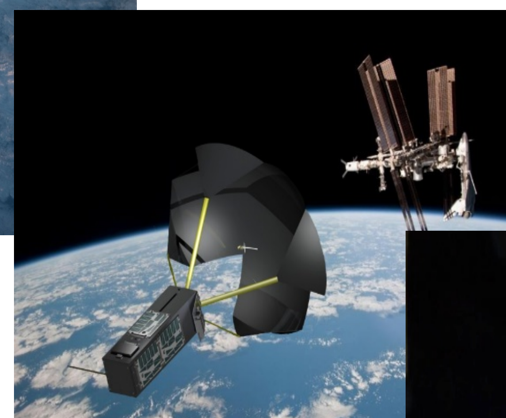


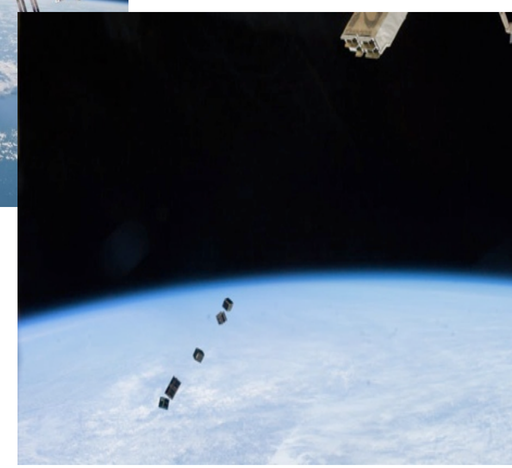


C. Glass (LaRC) – DSMC preliminary results
H= 126km,Kn=10; H=88km, Kn=.025

Motivations

Pioneering the Use of the International Space Station as a Nanosatellite Deployment And Technology Platform

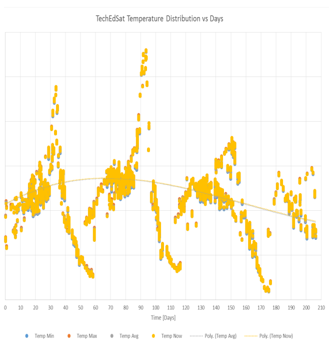


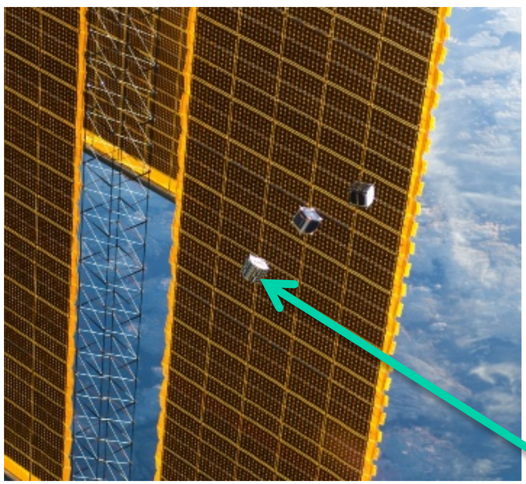


Next-Up!

TechEdSat -1

Vehicle:	HTV-3
Date:	10-4-2012 (launch 4-14-2012) ~7 month duration
Approach:	Single 1U cubesat launched from the ISS
Experiments:	Rad-tolerant architecture/COM; ISS Safety Methodology





TechEdSat 1

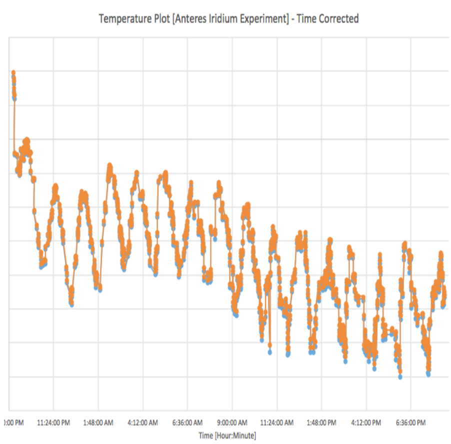
Key Attributes:

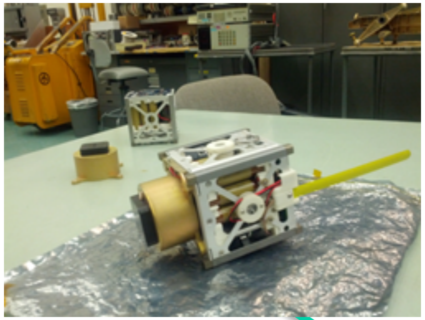
- First U.S. Cubesat jettisoned from the ISS
- 2-tier rad-tolernant architecture (AAC Microtec)
- COM (UHF, Iridium/OrbCOM (disconnected)
- ISS Safety/Inhibit design verification
- Tracking/housekeeping data for future flights

Other Key Contributors: J. Cortez, D. LeVasseur, A. Cohen, K. Ramus, G. Trinh and C. Hartney.

TechEdSat -2

Vehicle: Antares-1
Date: 4-21-2012) ~ 1 day duration (experiment)
Approach: Single 1U cubesat/piggyback (PhoneSat)
Experiments: First Iridium COM experiment





Key Attributes:

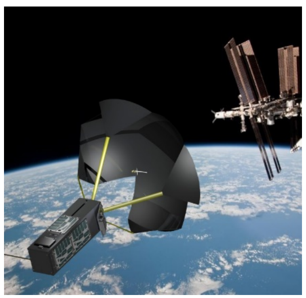
- First U.S. Cubesat jettisoned from Antares-1
- Single cubesat experiment (Phonesat)
- COM experiment
- Battery-operated Iridium experiment (short)
- Incremental test for future flights

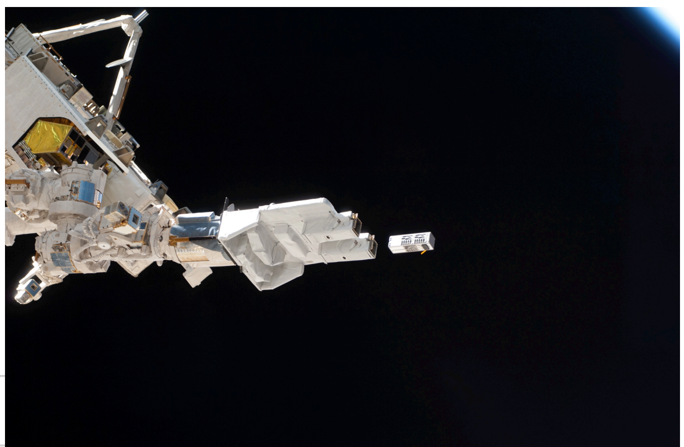
TechEdSat 2 (+Phonesat)

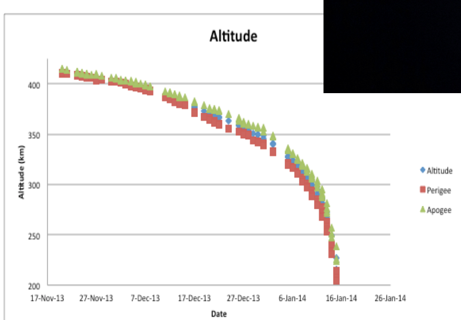
Other Key Contributors: K. Boronowsky, J. Benton, K. Ramus,

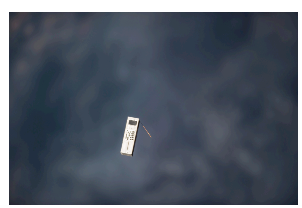
TechEdSat -3

Vehicle: HTV-4
Date: 11-23-14 to 1-6-2014 (Launch 4-20-2013)
Approach: 3U cubesat from JSSOD launcher
Experiments: **First** Exo-Brake flight test (1/10 scale)









Key Attributes:

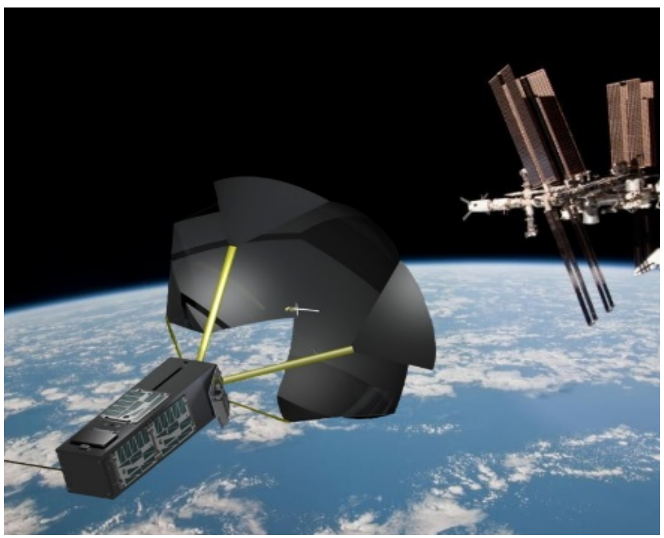
- First U.S. 3U Cubesat jettisoned from ISS
- Simple structural design/extrusion
- Unique safety inhibits (ALI switches)
- COM/gps experiment
- Four strut Exo-Brake (.3m^2)
- Dual architecture/ UHF back-up
- Exo-Brake β=7.5 kg/m^2

TechEdSat 3

Other Key Contributors: A. Guarneros-Luna, P. Papadopoulos, D. Atkinson, A. Reuter, J. Mojica, J. Benson, M. Scales, G. Pearhill

TechEdSat -4

Vehicle: HTV-5
Date: 3-4 to 4-3-2015 (Launch 8-4-2014)
Approach: 3U cubesat from NRCSD laucher (NanoRacks Cube-Sat Deployer
Experiments: Second Exo-Brake flight test (1/10 scale); Email control



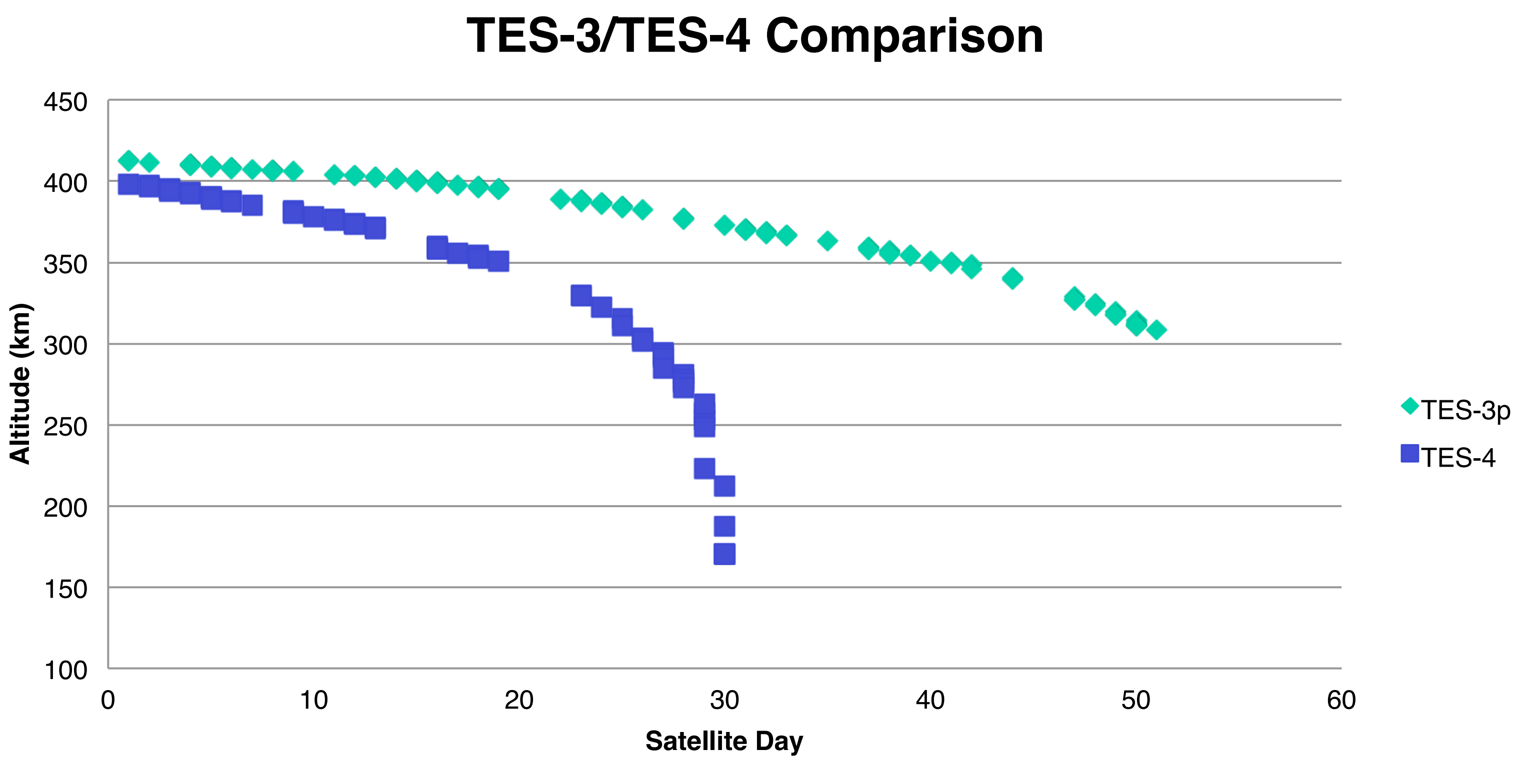
Key Attributes:

- First U.S. 3U Cubesat jettisoned NRCSD
- Simple structural design/extrusion
- Unique safety inhibits (ALI switches)
- COM/gps experiment
- Dual strut Exo-Brake (.3m^2)
- Dual architecture/ Iridium modems
- Exo-Brake β=6.0 kg/m^2

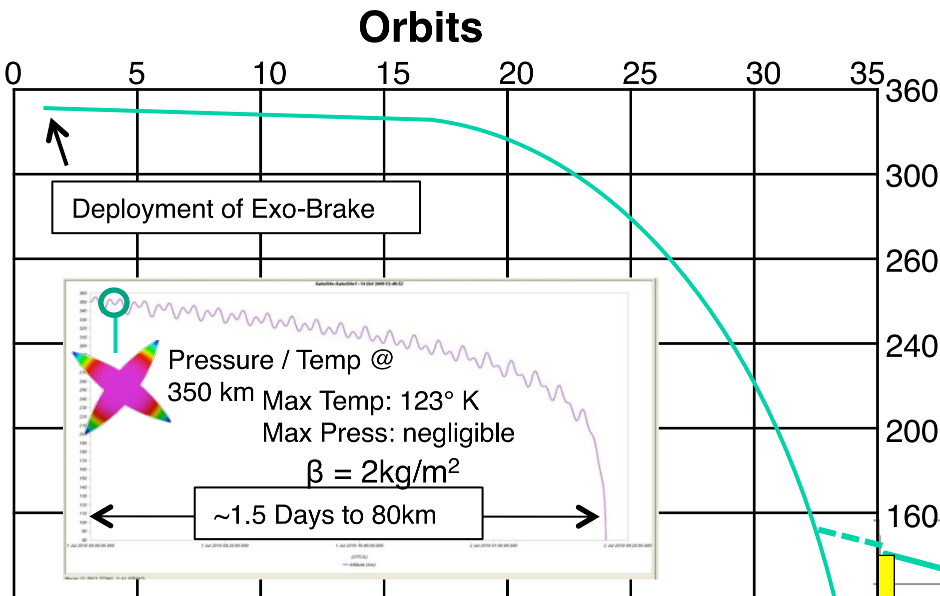
TechEdSat-4

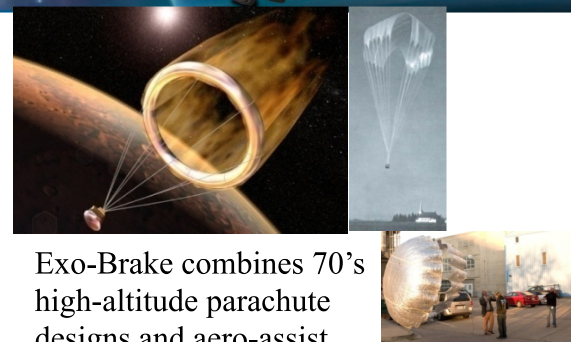
Other Key Contributors: A. Guarneros-Luna, P. Papadopoulos, D. Atkinson, A. Reuter, J. Mojica, J. Benson, M. Scales, j. Seneris, A. DiQuattro, K. Sok, G. Pearhill

TechEdSat -4



Other Key Contributors: A. Guarneros-Luna, P. Papadopoulos, D. Atkinson, A. Reuter, J. Mojica, J. Benson, M. Scales, j. Seneris, A. DiQuattro, K. Sok, G. Pearhill

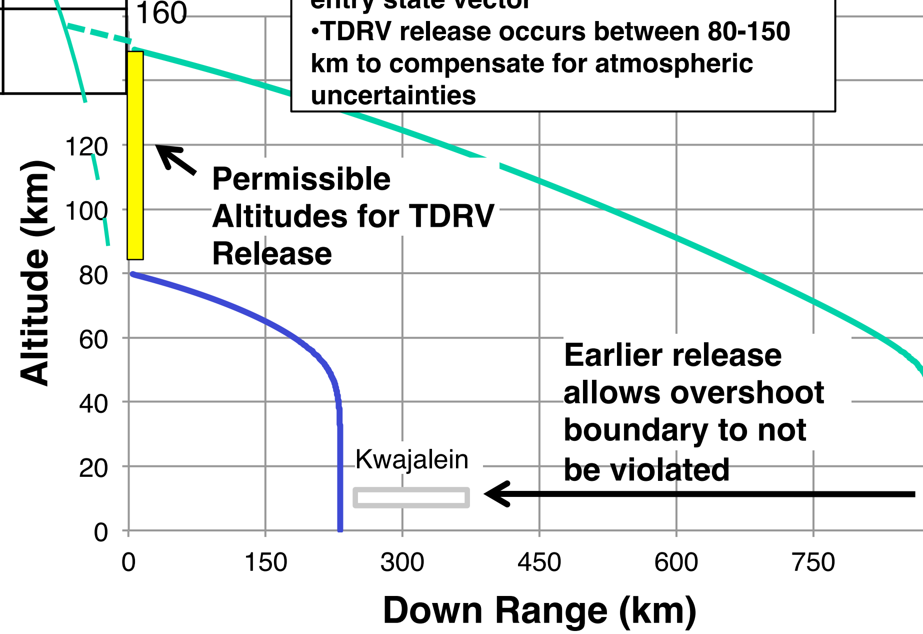


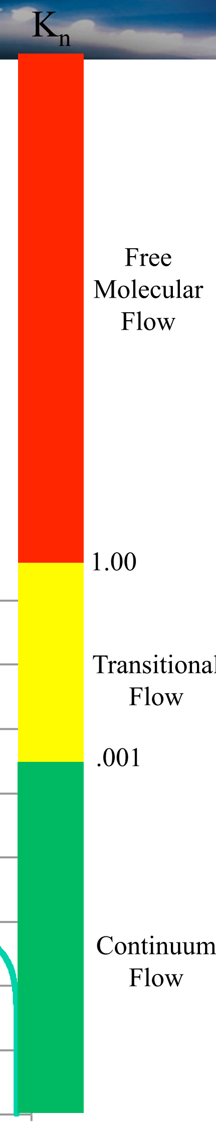


Exo-Brake combines 70's high-altitude parachute designs and aero-assist concepts

Control Strategy

- **GPS/Tracking permits selection of TDRV entry state vector**
- **TDRV release occurs between 80-150 km to compensate for atmospheric uncertainties**





SOAREX-8
(1/2 scale SPQR)

After rapid deployment, the Exo-Brake becomes a High temperature cross-parachute.
*Not to scale

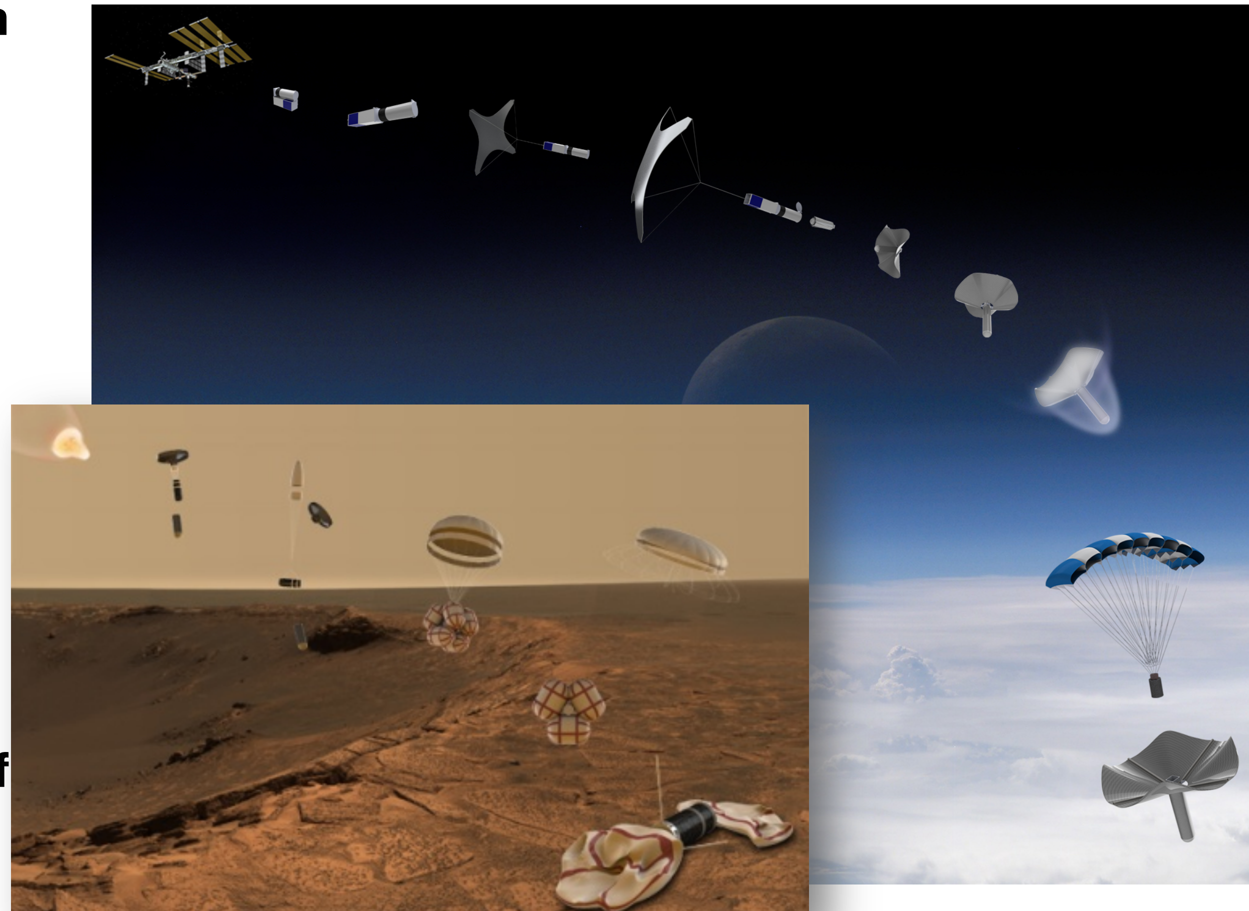
*Note: Times / Altitudes between graphs are not to scale

Applications

ISS Small Sample Return (SPQR)

3 stage concept

- **On-demand sample return**
- **COM IV experiment**

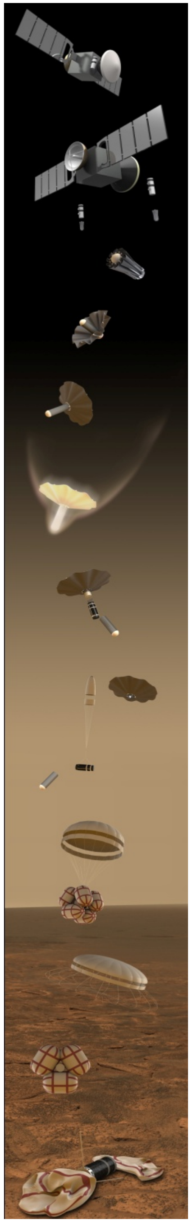


Re-entry test-bed

Atromos: Cubesat Mission to the Surface of Mars

Summary

- **TES-N series has helped to train ~40 individual now at NASA, SpaceX, Boeing, Lockheed and …Start-ups!**
- **Methods for 'Rapid Proto-flight' developed**
- **Low cost/ high ROI approach/ incremental test**
- **Numerous Technologies Advanced**
  - COM, 'Long-downrange' for re-entry technology
  - Fabrication/evolutionary approaches
  - De-Orbit Systems (Exo-Brake)
  - Evolving 2-tier Architecture
- **Pioneered ISS Safety Processes for Satellite Jettison**
- **Future Work leads to ISS Sample Return, Advance Re-entry Development ….. And Mars!**



References

Key References:

Marcus S. Murbach, "SCRAMP: The Development of an Advanced Planetary Probe from CFD to Re-entry Test Flight," International Planetary Probe Conference, Athens, Greece, June 27-July 1, 2005.

M.Murbach, et al, "ATROMOS - An Innovative Mars Polar Science Mission," NASA Ames Research Center, July 30, 2006.